Reservoir Characterization Using Acoustic Impedance (AI) Seismic Inversion and Seismic Multi-Attribute, Case Study: "BM" Field, Bintuni Basin, West Papua

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Abstract. "BM" Field is one of the oil and gas field at Bintuni Basin, West Papua, Indonesia. This field produced crude oil, that is originated from Late Miocene Kais Formation limestone. Other than crude oil, this field also has natural gas potential from Roabiba Sandstone reservoir in Jurassic Lower Kemblangan Formation. Reservoir characterization can be done using two main types of data which are seismic data, well log data, and supported by geological data. There are two methods that can be used together in integrating seismic and well log data which are acoustic impedance seismic inversion and seismic multi-attribute. The processes started with sensitivity and petrophysical analysis of well logs data, followed by well seismic tie using both of seismic and well logs, and finally structural interpretations of the seismic data. Seismic inversion process will distribute AI value, that has been analyzed as correlated to the porosity data, to all the seismic lines. Seismic multi-attribute will also use the inverted AI results as the external attributes and other trained seismic attributes to predict porosity parameter of the seismic lines that later will be distributed to the research zone. Analysis results showed that there is a positive flower structure that act as the hydrocarbon's trap and migration pathways. Targeted Kais Formation and Roabiba Sandstone zone AI value is in the range of 20.000-50.000 g.ft/cm.s with its dominant distribution direction is Northwest to Southeast. There is also an AI value anomaly on top of the Kais Formation that is indicated caused by shale dominance on top of Kais Formation. It is confirmed further by its absence on Kais Formation multi-attribute porosity map. According to the porosity map, Kais Formation's porosity value is in the range of 5-25%.
Keywords: seismic, inversion, multi-attribute, reservoir, porosity

1. Introduction

Energy is vital to human lives in this modern day. It is also related to the unstoppable growth of the human population each year. Of all of the energy needs around the world, 80% of the supply comes from oil and gas energy which are still irreplaceable. BM Field is one of the fields that is located in the Bintuni Basin. The first discovery in Bintuni Basin was the oil discovery in Kais Formation limestone and several years later the biggest gas discovery as of 23.6 MMSCFGPD was founded in Bintuni Basin inside Middle Jurassic sandstone, it also marked the first Mesozoic hydrocarbon discovery in Indonesia [1]. It is also identified that the BM Field area has a great petroleum system including its components and processes, that will support the occurrence and accumulation of hydrocarbon [2]. Reservoir characterization is one of the processes to describe quantitatively and qualitatively reservoir rock's characters using several data such as geology data, seismic data, and well log data. Two of the methods that can be used are Acoustic Impedance (AI) seismic inversion to determine reservoir rock's porosity using AI parameters and seismic multi-attribute to combine AI inversion parameter with the other seismic attributes to predict reservoir rock's porosity more accurately [3]. The results from both of the methods then will be analyzed and compared to determine prospect zones and hydrocarbon zone spread patterns. The petrophysical analysis results are validated using the core data of each well.

2. Data and Methodology

The three data that were used are geological, wireline logs, and 2D PSTM seismic data. Wireline log data was used to determine rock's porosity and shale volume by doing a petrophysical analysis. Starting from the shale volume determination using the gamma-ray log, as its value represents the rock's radioactivity that was affected by its shale components, followed by porosity determination for each well K-3, K-5, and KD-1 using the density-neutron method. The petrophysical analysis results were then validated using the core data of each well. The wireline log data was further used in the well seismic tie process to integrate its domain with the seismic data time domain. The KD-1 well's check shot data was used to tie all of the wells. Using 26 different distinct parameters wavelets with two extraction methods which are, statistical and use-well methods to find and determine the best parameters combination for the wavelet with the best correlation value across all of the wells.

The structural interpretation was carried out using the seismic data to determine faults and formation continuity (horizon) subsurface. It also must be correlated to the regional geology condition of the area. It is important to make sure that the well seismic tie process is carried out correctly before doing the structural interpretation. The output of the process was time structure maps on each of the targeted formations. The time domain structure maps then were converted into distance domain to make an easier analysis and inversion process using the velocity surface method and followed by further well-adjustment. The structural interpretation results are then used in the acoustic impedance (AI) seismic inversion. The inversion was used to predict reservoir rock's porosity using its AI parameters. Rock's AI parameters can be used to predict rock's porosity values based on their relationship which must be proven first using sensitivity analysis on the wireline log data [4]. The inversion process started by making an initial model to spread the AI parameters, which can be calculated from sonic (DT) and density (RHOB), on each well. Then, it was followed by the pre-inversion analysis to determine the correlation between the AI parameters from the wireline log data and the inversion results. In this research, the inversion was carried out by using a model-based inversion method, and the evaluation was done based on its error and correlation values [5].

The last process was the seismic multi-attribute analysis. This process predicted rock's porosity more accurately using a combination of multiple seismic attributes simultaneously [6]. The process included trial and error to determine the most optimal combinations of the seismic attributes. As a result, seven operators' lengths and eight maximum attributes were used in this process. It was done on each of the lines. It is vital to make sure that it is also geologically correct by correlating it with the geological data. After the correlation between the predicted logs and the original log values was decent and acceptable, it was decided to apply the multi-attribute to the seismic data. Both methods' results, then were analyzed and compared to determine the prospect zones as well as the reservoir rock's porosity distribution.

3. Results and Discussion

Clay Volume (VCl) and Porosity Log Calculation

The clay volume log was calculated using the gamma-ray log, so it was done along the gamma-ray log interval in each well. The result showed low clay volume tendencies inside the targeted zone as the porous zone would correlate with low clay content. On the other hand, the porosity log calculation was done by using the density-neutron method which is based on the correlation of density log and neutron porosity log to determine the porosity values.

As can be seen in Table 1. is the results of clay volume and porosity calculation in Kais Formation and Roabiba Sandstone from each well. Starting with the Kais Formation, the average clay volume for each well is 0.25 on KD-1, 0.23 on K-3, 0.28 on K-4, and 0.15 on K-5. The porosity value average is 18.16% on KD-1, 11.45% on K-3, 4.4% on K-4, and 5.16% on K-5. The Roabiba Sandstone calculation could only be conducted on the KD-1 well since it was the only well that reached the Roabiba Sandstone interval. The clay volume average is 0.43 and the porosity value average is 8.4% on the KD-1 Roabiba Sandstone interval. The results showed that Kais Formation and Roabiba Sandstone intervals were great potential reservoir target zones with their low VCl tendencies and good porosity value.

Table 1. Clay volume and porosity log calculation results

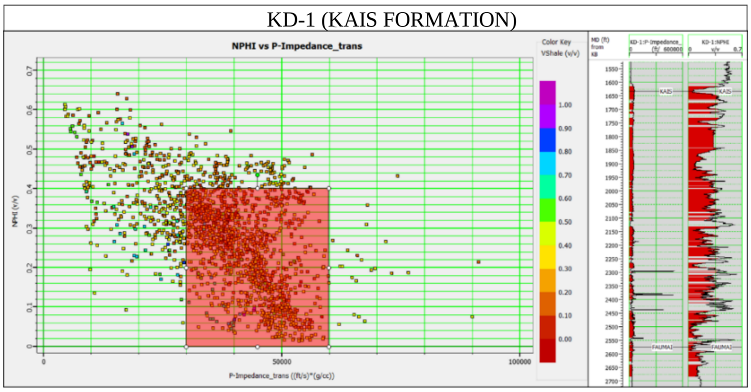
Well	Interval	VCl (v/v)	Phie (v/v)
KD-1	Kais	0.25	18.16%
	Roabiba Sandstone	0.43	8.4%

K-3	Kais	0.23	11.45%
K-4	Kais	0.28	4.4%
K-5	Kais	0.15	5.16%

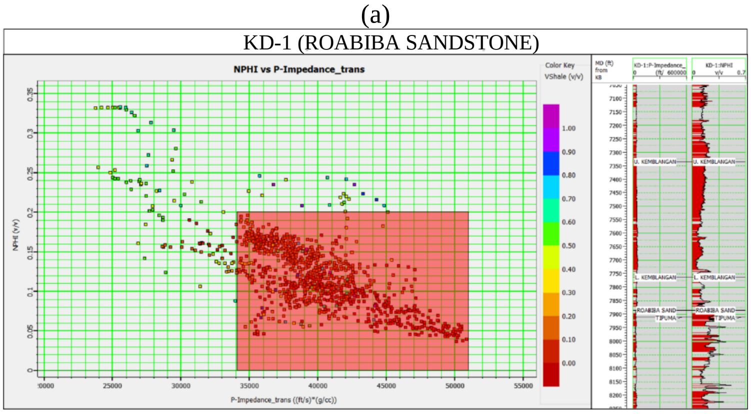
Sensitivity Analysis

The sensitivity analysis is vital in lithology and reservoir zone delineation. The correlation between acoustic impedance and porosity correlation was also determined by this process. According to the analysis results, as shown in Figure 1 and Figure 2, it could be identified the reservoir zone, which is indicated by low gamma-ray log value, had high p-impedance and low neutron porosity value characteristics. A low gamma-ray log value is associated with limestone and sandstone as potential reservoir rocks.

According to the results, the data could be considered sensitive to separate porous and non-porous zone and also can be seen by its good lithology separation on the cross plot. Based on the data cross plot results, the lower threshold of NPHI value is 0.2 and the maximum threshold of p-impedance value is 34000 (ft/s)*(g/cc) for the Roabiba Sandstone interval, as for the Kais Formation interval the minimum threshold of NPHI is 0.4 and the maximum threshold of p-impedance is 300000 (ft/s)*(g/cc). This positive result showed that the data was possible to be used in the AI seismic inversion.



(a)



(b)

Figure 2. Data *crossplot* and *cross-section* (a) Kais Formation, (b) Roabiba Sandstone

Well Seismic Tie

Well seismic tie process was done by correlating seismic data's seismogram with the wireline log's synthetic seismogram data, evaluated by each wavelet with different parameters to determine the most suitable wavelet parameters across all the wells. There were a total of 26 wavelet parameters evaluated and the average correlation value from each wavelet evaluation was used to determine the best wavelet for all of the wells. The best wavelet that was tested had 0.734 correlation values coded as wavelet S.3.3. The chosen wavelet parameter, which is wavelet "S.3.3", can be seen in Figure 4. Then, the chosen wavelet was applied to the well seismic tie process and was evaluated on the seismic cross-section for each line.

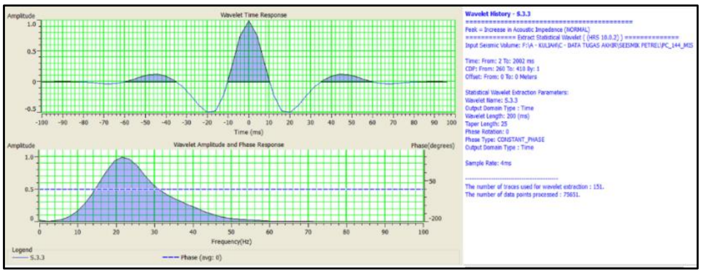


Figure 3. Wavelet S.3.3 parameters

Structural Interpretation

The interpretation process was first done on the wireline log data, the well's structural correlation showed the general structure information such as its layer's boundaries, lithology, and hydrocarbon contacts. Generally, the dominant structure is an eastern ascending pattern. It also confirmed the occurrence of strike-slip faults in the area according to the geological information. These faults had two main roles in the petroleum system, which are as a trap and hydrocarbon migration pathways.

A further interpretation was done to pick the faults and horizons on each of the seismic line data. Fault interpretation was done by connecting the discontinuity points of each reflector to get geological faults, which resulted in sixteen rising faults on all of the seismic lines. It also confirmed the occurrence of the positive flower structure in the area. On the other hand, the horizon interpretation was focused on four targeted zones which are Top Kais, Top Tipuma, Top Roabiba, and Top Faumai. Both of the interpretation results then will be converted into a surface for each of the horizon targets. The final output is time structure maps that can be seen in Figure 4 on each of the targeted tops.

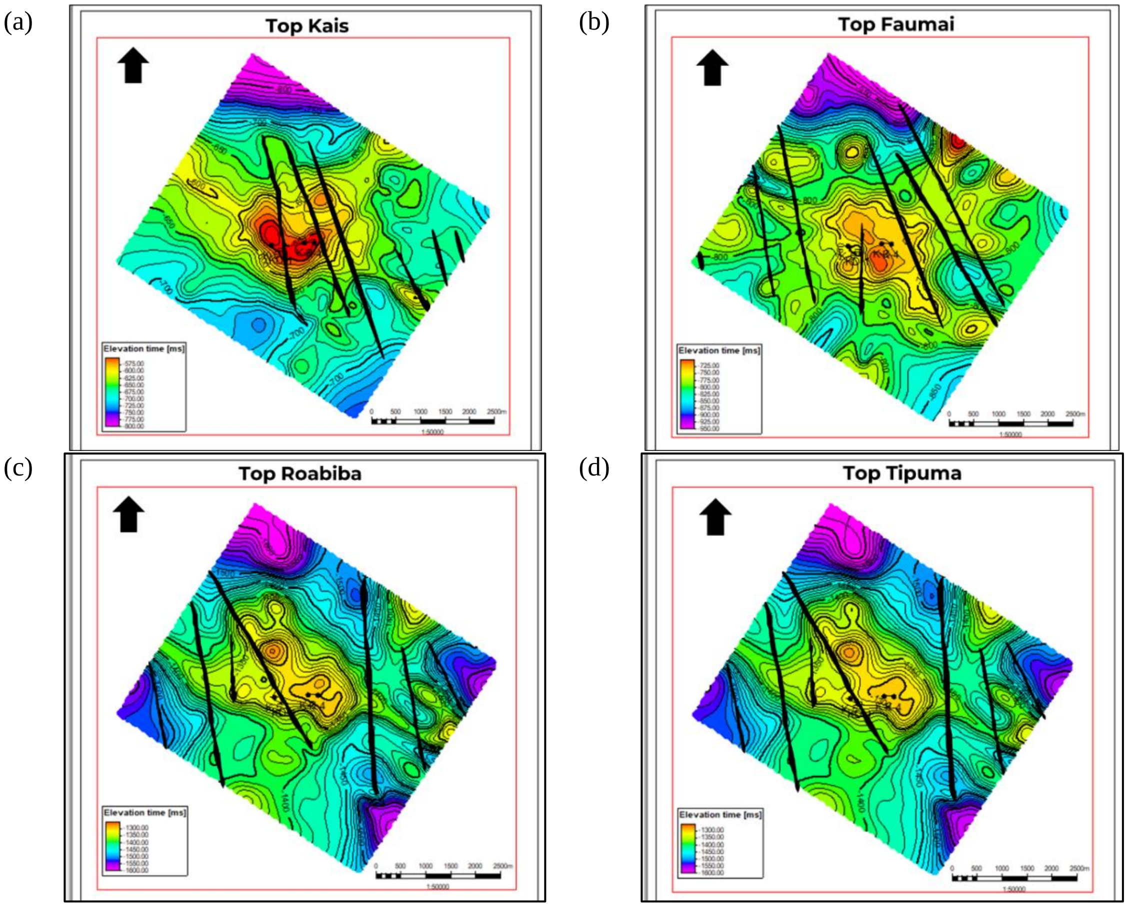


Figure 4. Targeted tops time-structure maps (a) Top Kais, (b) Top Faumai, (c) Top Roabiba, (d) Top Tipuma

Domain Conversion

The resulting time-structure maps from the structural interpretation process were still in the time domain, so they had to be converted into the depth domain. The analysis showed that the velocity surface conversion resulted in a better average offset between the well marker's depth and its conversion results depth. The final converted surfaces then were further corrected by eliminating the rest of the offset between the well marker and the depth conversion result. The final conversion output was depth-structure maps that would help for the following processes and the analysis on its own.

Acoustic Impedance (AI) Seismic Inversion

Model-based inversion method was carried out using an initial model for each of the seismic lines. It is also controlled by all of the wells and the interpreted horizons. The pre-inversion analysis showed a great correlation between the initial model and the predicted p-impedance logs with an average correlation of 0.9062 and an average error of 0.4178 across all the wells and seismic line combinations. The seismic inversion was carried out on all of the seismic lines. The resulting AI inversion was then extracted on each of the targeted horizons to get the lateral AI value distribution as can be seen in Figure 5. The AI value range on Top Kais is 20.000-40.000 g.ft/(cm/s) that is highlighted by light blue colors to orange, as for the Roabiba Sandstone AI value range is 36.000-50.000 g.ft/(cm.s) that is highlighted by green to dark orange colors. These high AI value distributions are correlated with the prior analysis result that showed both of these intervals as reservoir zones.

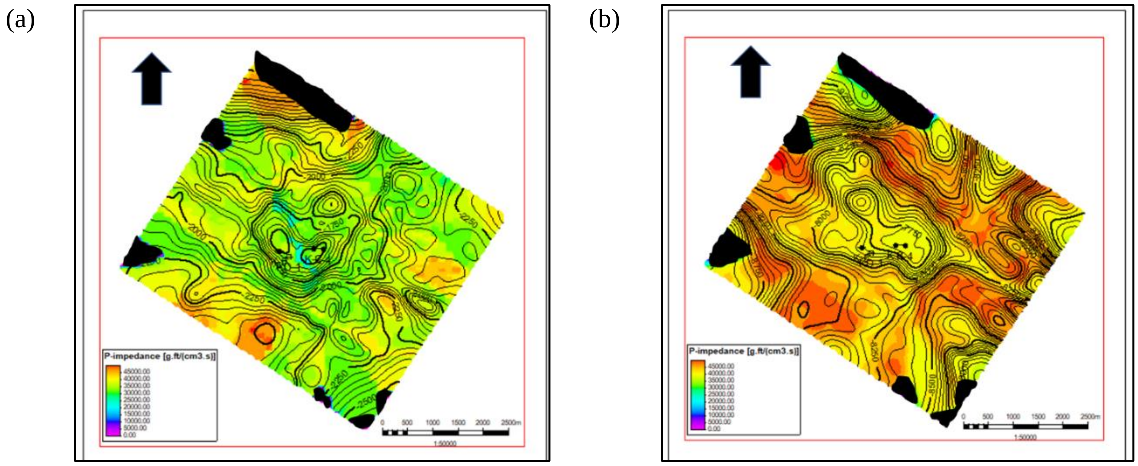


Figure 5. AI distribution map overlaid by depth structure map (a) Top Kais, (b) Top Roabiba

Seismic Multi-Attribute Analysis

Seismic multi-attribute analysis was used to predict porosity value distribution on each of the targeted tops using the combination of several seismic attributes and the AI seismic inversion results. The linear regression method was used to determine the optimal number of attribute combinations that would be validated by its error and correlation value. The result of the analysis process is an average error of 8.9275% and an average correlation value of 0.7413, regarded as an acceptable value the porosity prediction result could be used to identify the porosity distribution on each of the targeted tops.

The porosity prediction distribution can be seen in Figure 6. on Top Kais and Top Roabiba. According to the porosity map, the Top Kais porosity value range is 5-22% and the Top Roabiba porosity value range is 5-25%. The porosity distribution correlated with the prior analysis results confirmed further limestone lithology in the Kais Formation zone and sandstone lithology in the Roabiba Sand interval. It also shows southwest to southeast porosity distribution patterns as well as some porous closure areas. The porosity distribution map comparison between these two methods showed a bit of difference, more importantly in the anomaly occurrence in the middle of the research area of the AI seismic inversion porosity map. According to the prior geological study, the peak closure structure should show a high

AI value as it correlated with high porosity but in truth, it showed otherwise. It is indicated that the anomaly was caused by the high clay content on top of the Kais Formation around the anomaly's area since high clay volume also correlated with low AI value. That is why in this BM Field assessment, the seismic multi-attribute analysis method to predict porosity distribution is needed to be done since the AI inversion resulted in anomaly occurrence. Both of the top targeted zone's porosity is in the range of 5-25% which is bad to good according to Koesoemadinata's classification in 1978 [7].

4. Conclusions

Based on the analysis results can be summarized:

(a) Subsurface geology structure is dominated by dextral strike-slip faults that created the positive flower structure.
(b) The range of AI value distribution is 20.000-40.000 g.ft/(cm.s) on Top Kais and 36.000-50.000 g.ft/(cm.s) on Top Roabiba. With an AI value anomaly occurrence in the middle of the Top Kais Formation, it is indicated to be affected by clay content domination near the top boundary of the Kais Formation. It is also confirmed by its absence on the seismic multi-attribute porosity map.
(c) High AI value correlated with porous zones with the same distribution pattern as the multi-attribute map which is southwest to the southeast. The porosity value result is in the range of 5-25% and geologically more accurate compared to the seismic inversion result.
(d) High-value porosity and AI points are located in the southwest to the southeast dominant pattern which are great potential reservoirs on BM Field.

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